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ROCKET PHOTOGRAPHY

REPORT NO. 2

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PHOTO INTERPRETATION AND PHOTOGRAMMETRY
OF HYPERALTITUDE PHOTOGRAPHY

Contract No. NAS5-3390

Page	Line	
5	20	for "is part of the interior" read "is part of <u>an</u> interior"
9	10	for "25a red" read "25<u>A</u> (red)"
20	24	for "Fig. 2" read "Fig. <u>3</u>"
34	4	for "erosian" read "erosi<u>o</u>n"
62	8	for "thier" read "the<u>i</u>r"
63	24	for "possible" read "possibl<u>y</u>"
69	12	for "bases" read "<u>c</u>ases"
74	6	after "Report No. 1", insert "LR 17491, Contract NAS5-3390"
74	33	for "36 pp." read "p. 36"

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PHOTO INTERPRETATION OF WHITE SANDS ROCKET PHOTOGRAPHY

REPORT NO. 2

by

Paul M. Merifield
James Rammelkamp

CONTRACT NO. NAS5-3390

Contract Title

PHOTO INTERPRETATION AND PHOTOGRAMMETRY
OF HYPERALTITUDE PHOTOGRAPHY

March 1964

LR 17666

Prepared For
National Aeronautics & Space Administration
Goddard Space Flight Center
Greenbelt, Maryland

Attention: Dr. J. A. O'Keefe, Code 640
Dr. P. D. Lowman, Jr.

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CONTENTS

Section		Page
1	INTRODUCTION	1
2	INTERPRETATION OF V-2 NO. 40	5
	2.1 Photogeology of Jornada Del Muerto Basin and Rio Grande Depression	5
	2.2 Photogeology of the "Malpais" Lava Area	16
	2.3 Photogeology of Otero Mesa and Guadelupe Mountains Area	22
3	INTERPRETATION OF VIKING 11 PHOTOGRAPHY	29
	3.1 Photogeology of El Paso Region	29
4	INTERPRETATION OF VIKING 12 PHOTOGRAPHY	37
	4.1 Physiographic Photo Interpretation of Southwest Arizona and Part of Southern California	37
	4.2 Photogeology of Gila-San Francisco River Region, New Mexico and Arizona	44
	4.3 Photogeology of Mimbres Mountains and Vicinity, New Mexico	51
5	INTERPRETATION OF 1963 NASA AEROBEE PHOTOGRAPHY	58
	5.1 Photogeology of White Sands National Monument	58
	5.2 Photo-Interpretation of Apparent Landslide Phenomena, Otero Mesa New Mexico	63
6	CONCLUSIONS	68
Appendix A	Some Remarks on Photographic Systems and Minimum Resolution	71
	A.1 Table A-1 — Information From Rocket Photography	73
	CITED REFERENCES	74
	UNCITED REFERENCES	76

ILLUSTRATIONS

Figure		Page
1	Index Map Showing Rocket Photography Coverage	2
2	Geologic Map of Part of South-Central New Mexico	8
3	V-2 No. 40 Photo of Jornada Del Muerto and Vicinity	10
3a	Photogeologic Interpretation Showing Mappable Beds, Faults, Folds, Drainage	11
4	V-2 No. 40 Photo of "Malpais" Lava Flow and Vicinity	18
4a	Photogeologic Interpretation Showing Pahoehoe Lavas, a Pediment, and an Anticline	19
5	V-2 No. 40 Photo of Otero Mesa and Guadelupe Mountains Area	24
5a	Photogeologic Interpretation Showing Possible Landslide Phenomena and Karst Features	25
6	Viking 11 Photo of El Paso Region	31
6a	Photogeologic Interpretation Showing Tectonic Lineaments and Volcanic Features	32
7	Viking 12 Photo of Parts of Southern Arizona, California, and Mexico	39
7a	Photo Interpretation of Physiographic Features Showing Major Faults and Axial Trends of Mountains in Basin and Range Province	40
8	Viking 12 Photo of Gila - San Francisco River Region, New Mexico and Arizona	46
8a	Photogeologic Interpretation Showing Tectonic Lineaments and Lava Flows	47
9	Viking 12 Photo of Mimbres Mountains Vicinity, New Mexico and Arizona	53
9a	Photogeologic Interpretation Showing Dip Slopes and Two Types of Playas	54
10	Aerobee Photo of Part of White Sands National Monument	60
10a	Photogeologic Interpretation Showing Differentiation of Sand Deposits	61
11	Aerobee Photo of Part of Otero Mesa New Mexico	65
11a	Photo-Interpretation Showing Apparent Landslide Phenomena	66

SYMBOLS

Contact

Dashed where approximately located

Indefinite Contact

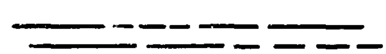
Queried where location is uncertain

Concealed Contact

Queried where location is uncertain

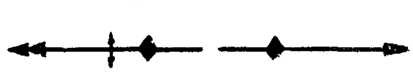
Lineament

Probable fault or fracture — may be partially or completely covered. Inferred from linear topographic features.



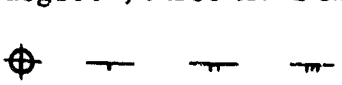
Ridge or Crest

Showing crest line. Indicates generalized axis of mountain ranges and highlands. Tapered end indicated by arrowhead. Short double — headed arrow crossing main ridge line indicates probable underlying anticline with plunge denoted by double arrowhead at tapered end.



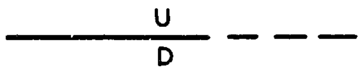
Postulated Strike and Dip

Crossed circle indicates dip of 0 to 5 degrees. One tick-mark indicates 5 to 30 degrees; two ticks indicate 30 to 60 degrees; three ticks indicate 60 to 90 degrees.



Fault

Offset of surface — dashed where approximately located. Queried where location is uncertain.



Fold

Volcano

SECTION 1

INTRODUCTION

PURPOSE AND PLAN OF THE REPORT

This report deals with the interpretation of photography returned to Earth from rockets launched at the White Sands Proving Grounds, New Mexico. The purpose of the study is to help define the role of hyperaltitude photography in determining the physical characteristics of planetary surfaces. The approach is an empirical one. Available photographs taken at altitudes between 70 and 200 km are analysed to determine what physical features can be identified, and what problems in interpretation are peculiar to photography from great altitudes. Little attention was paid to man-made features and interest was focused on such natural features as drainage patterns, geomorphic landforms, surface composition, relief and texture, and geologic structure. In addition to the purely descriptive aspects of the photos, special interest was given to information which was previously unknown or difficult to obtain by other means.

The photographs used in this study were taken by the V-2 No. 40 rocket (1948), the Viking 11 rocket (1954), the Viking 12 rocket (1955), and the NASA Aerobee rocket (1963). The Aerobee rocket carried a Maurer 70 mm camera; the others carried the K-25 aircraft camera. Infrared film was used except for the V-2, No. 40 flight.

The photographs cover a large portion of the southwestern United States and Sonora, Mexico. (See Index Map, Fig. 1). In general this region has a subarid to arid climate. Vegetation is restricted largely to the flood plains of large

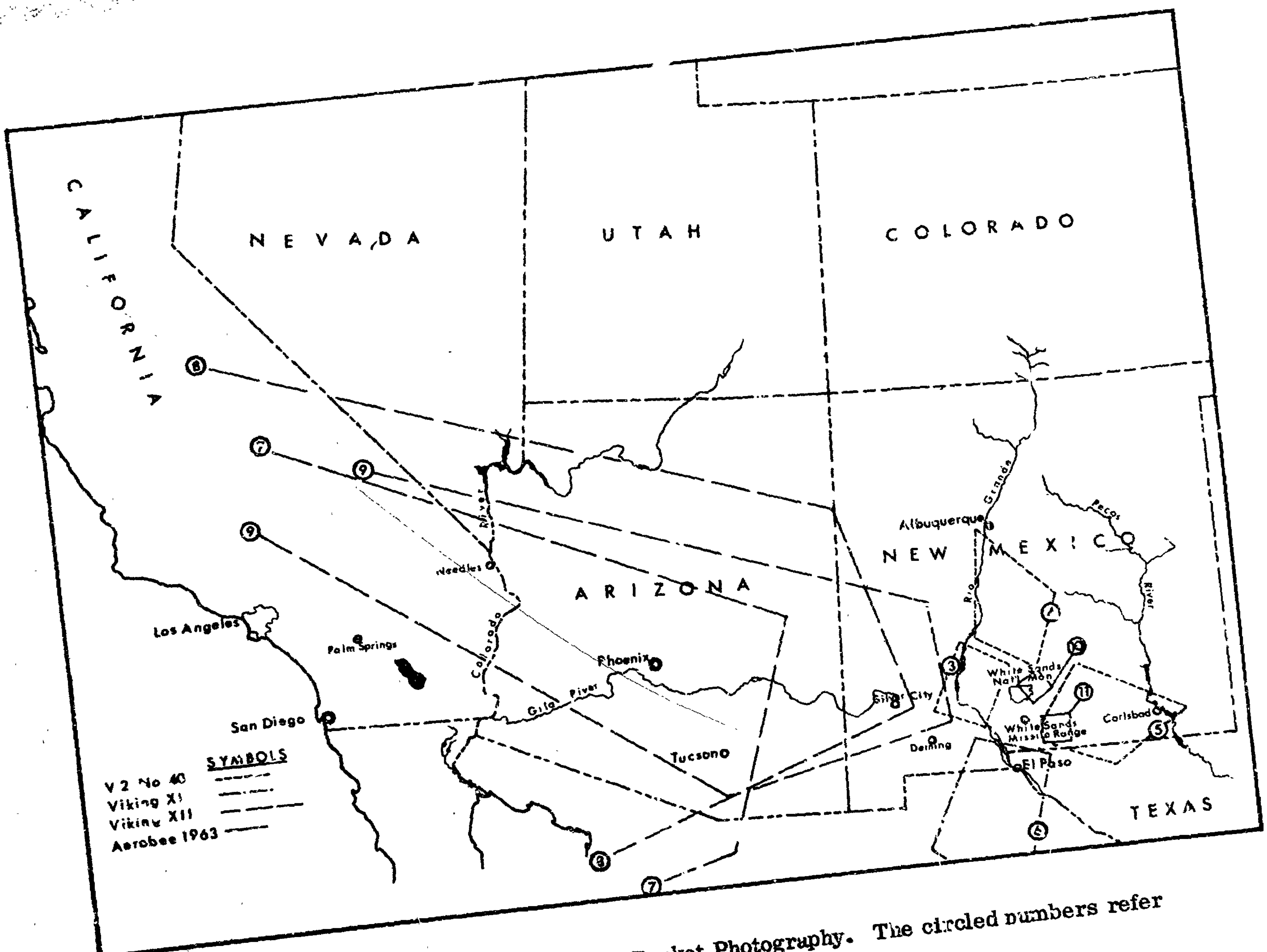


Fig. 1 — Index Map of White Sands Rocket Photography. The circled numbers refer to the figures in the report.

rivers and to high mountains or plateaus. Structural features of the region include the stable Colorado Plateau, which extends into northern Arizona and northwestern New Mexico, and the Basin and Range Province to the west and south of the Plateau. Many of the basins have interior drainage, resulting in the formation of large playas. Well-developed pediments and alluvial fans extend from the ranges outward into extensive bolsons, some of which are tens of miles in breadth. The region is well-suited to photogeologic interpretation because of the diversity of the geology, the prominant outcrops, and the lack of vegetation.

Coverage of many different physiographic provinces would be required for a complete analysis of hyperaltitude photography; unfortunately, relatively few hyperaltitude photographs are available. The Mercury-Atlas photography fills some gaps, but more and better photographs are needed before a comprehensive library can be established, containing representative photographs of the entire surface of the Earth. Such a library would be useful in the interpretation of photography of Mars and perhaps other planets and moons.

PREVIOUS WORK

Early photography obtained with V-2 and Aerobee rockets in the late nineteen forties has been discussed by Holliday (1954). Baumann and Winkler (1955, 1959) reported on the photographic experiments of the Viking 11 and 12 rockets. The resolution of these photographs was also discussed by Katz (1960). The photogeology of some of the White Sands photographs has been treated by Merifield (1963) and briefly by Lowman (1963). The seemingly small amount of interpretive work with hyperaltitude photographs, coupled with the anticipated valuable applications of such photographs, has prompted this study.

ACKNOWLEDGEMENTS

The authors are grateful to Dr. Paul D. Lowman Jr., N.A.S.A. (Goddard Space Flight Center), and Mr. Clyde Holliday, Applied Physics Laboratory, The Johns Hopkins University, for assisting in the acquisition of the photographs.

SECTION 2

INTERPRETATION OF V-2 No. 40 PHOTOGRAPHY

2.1 PHOTOGEOLOGY OF JORNADA DEL MUERTO BASIN AND RIO GRANDE DEPRESSION

The photograph in Fig. 3 was taken at an altitude of 116.7 km* from a V-2 rocket launched from White Sands Proving Grounds on July 26, 1948 at 1103 MST. The photographic system consisted of a K-25 aircraft camera loaded with Aerographic Super XX film, type C sensitizing, and a 25-A (red) filter.

The coverage is approximately 3000 square miles and is centered 47 miles northwest of the town of White Sands. The optical axis was tilted approximately 25.5° along an azimuth of N 65° W. The distance across the center of the picture is about 50 miles.**

Considerable geologic information is recorded in the photograph. As an experiment, the photograph was first interpreted without referring to existing maps or literature. The preliminary interpretation is discussed and then compared with geologic maps of the region.

A major portion of the area is covered by surficial deposits characterized by a light, rather even tone. In the lower part of the photograph at L (delineated by the dotted line), a flat barren area lacking gully systems is visible which is part of the interior drainage basin. Apparently, the basin is about to be captured by the Rio Grande River, which traverses the upper and left portions of the photograph. This observation is suggested by the tributaries encroaching near M. The essentially horizontal surface near N at the south end

*Clyde Holliday, written communication.

**See Report No. 1 (LR 17491) under this contract for a complete discussion of the scale of oblique photographs.

Fig. 2 – Geologic map of part of south-Central New Mexico, vicinity of Jornada Del Muerto Basin. From U.S. Geological Survey Map entitled, "Preliminary Geologic Map of the Southwestern Part of New Mexico" by Carl H. Dane and George O. Bachman, 1954, U.S.G.S. Misc. Geol. Investigations, Map I-344.

The outlined area shows the coverage of fig. 3, V-2 No. 40. The Jornada Basin is on the right-center, bisected by the New Mexico Principal Meridian. The Rio Grande, Caballo Reservoir and the Caballo Mountains occupy the center of the map. the San Andres Mountains are on the right, and the Mimbres Mountains are on the bottom left.

EXPLANATION

(Only major units are listed)

Quaternary

Qab	–	Alluvium and other surficial deposits
QTs	–	Sante Fe Group – Unconsolidated and consolidated brown, red, and gray silts and gravels, some volcanic flows
Qb	–	Basalt, massive to vesicular

Tertiary

Ta	–	Rubio Peak formation – andesite, basalt, and latite

Cretaceous

Kmv	–	Mesaverde Group – varicolored sandstone and shale
Kdm	–	Mancos shale and Dakota sandstone

Triassic

Tr	–	Triassic rocks – undifferentiated, varicolored sandstone, and shale

Permian

Psa	–	San Andres limestone
Py	–	Yeso formation – silty sandstone, gypsum some limestone
Pa	–	Abo sandstone – dark-red or reddish brown mudstone and sandstone

Pennsylvanian

IP — Pennsylvanian rocks, undifferentiated – limestones, shales, and sandstone

Precambrian

pC — Precambrian rocks, undifferentiated – pink to gray granite, gneiss, schist, and quartzite

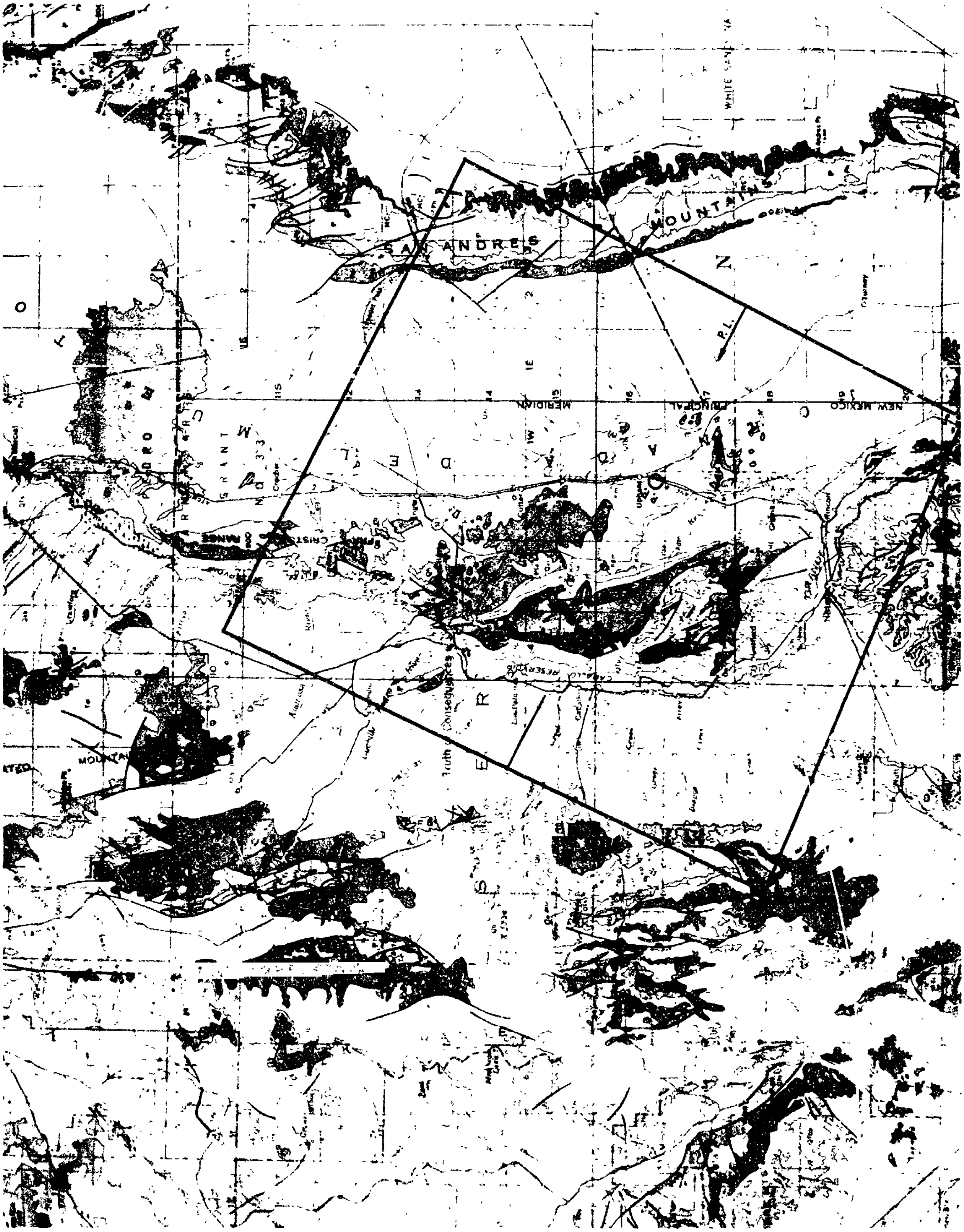


Fig. 2 – Geologic Map of South-Central New Mexico – Area surrounding Jornada Del Muerto Basin, Elephant Butte and Caballo Reservoirs.

V-2 NO. 40

Figs. 3 and 3a — Photogeologic interpretation of Jornada Del Muerto basin and Rio Grande depression, showing mappable beds, faults, folds, drainage

Tilt (approx.)	25.5°
Direction of Principal Line (approx.)	N 65° W

Camera	–	K-25 aircraft
Filter	–	25 a red
Lens	–	163 mm focal length
Film	–	Aerographic Super XX with Type C Sensitizing

KEY TO LOCATIONS

L	Interior drainage basin
M	Rio Grande tributary drainage encroaching on interior basin
N	Old alluvial surface - possible old floodplain
O	Trellis-dendritic drainage pattern, bedding control
P	Trellis-dendritic drainage pattern
Q	Volcanic highlands
R	Volcanic highlands
S	Volcanic highlands
T	Fault control of drainage, stream offsets
U	Deep arroyos

Fig. 3


ELEPHANT BUTTE RESE
RESERVOIR
Kmv
Km

of the basin is evidently a remnant of an older valley floor which was at one time much more extensive - possibly an old flood plain of the Rio Grande. The horizontal attitude of this surface is deduced from the rather distinct scarp or bluff line indicated on the annotated halftone. This rather persistent scarp is not notched by any major drainage channels, but is still three to four kilometers east of the river. The front slope of the scarp is steep, with a fine-textured drainage network fanning out from the base of the scarp. These features imply that poorly consolidated materials which are continually sloughing away, underlie the flat upper terrace or bolson surface, and that a relatively hard terrace cap or hardpan is protecting the steep slope along the edge of the scarp. The flat terrace surface is streaked with white, suggesting wind-blown sand or dry lake deposits.

A rather complex drainage pattern is displayed in the photograph. Considering the whole area, two major collecting basins are evident, the major one being the valley of the Rio Grande, and the other one being the interior drainage basin in the center of the bolson. The channels emptying into the Rio Grande are in general sub-parallel with relatively steep valley walls. These streams are evidently consequent and are gradually developing subsequent branches in a trellis pattern, seeking out underlying structural weaknesses.

The interior basin is named the Jornada del Muerto, or "Journey of Death" and affords the opportunity of studying two contrasting drainage patterns in close association. The drainage at P on the northwest slope of the basin has a modified dendritic pattern, almost trellis-like, indicating partial bedding control by underlying strata that strike roughly perpendicular to the slope. The alluvial cover in this gently sloping area is very thin, with exposed bedrock showing in patches. On the east side of the basin the drainage is parallel to the broad alluvial slope. Few tributaries and the lack of drainage integration indicate youth and lack of bedding control. Indeed, the general parallelism of the main channels and the occasional anastomosing pattern of some of the small tributaries indicate a youthful stage of drainage development in deposits of probable granular alluvium. Many of the smaller channels seem to simply disappear before reaching the bottom of the basin, suggesting good subsurface drainage. Also, the braided pattern of small channels is characteristic of an arid hydrologic regime in an area of rising base level.

Another interesting drainage pattern is seen immediately west of the lower reservoir (Caballo Reservoir) on the west slope of the Rio Grande Valley. Several large, straight and deeply incised arroyos plunge down a relatively steep slope to the Rio Grande. The straightness and depth of the main channels, and the finer-textured dendritic pattern of the tributaries point to an underlying rock of relatively poor induration such as sand, silt, or ash, possibly capped in some areas by a harder surface stratum. Two straight and deep channels are seen at U. The walls of these intermittant drainage channels are steep and quite high, possibly 100 feet or so as a guess. Only a relatively few, short tributaries join the main channels. From the foregoing characteristics it is concluded that only infrequent but very intense storm precipitation has developed these youthful channels. Particularly noticeable is the apparent absence of any sizeable alluvial fans at the foot of the large arroyos where they intercept the Rio Grande floodplain. This condition is to be expected in the narrower stretch of the Rio Grande Valley near the two reservoirs, where the arroyos empty more or less directly into the Rio Grande. In that area, the river apparently was continuing to downcut before the reservoirs were constructed. Near the bend of the river, south of the Caballo Reservoir, the recent floodplain truncates the adjacent arroyos. The Rio Grande appears to be continuously reworking the more recent alluvial fans which were built along the edge of the floodplain.

Bedrock outcrops are characterized by a wide variety of tones and pattern elements. The most striking of these are the parallel and highly contrasting bands in the easterly corner of the picture which delineate cuestaform or hogback strata of a westerly-dipping, sedimentary sequence. What is apparently the same sequence in reverse is exposed on the opposite side of the interior drainage basin near the center of the picture.

Dark-toned lavas form highlands at Q, R, and S in the upper left and central-left portions of the picture. Lavas and associated volcanoes also occur near the center of the basin. The youngest consolidated rocks are apparently those bordering the Rio Grande on the west bank near the reservoirs. As mentioned previously, the drainage pattern indicates that these rocks are poorly consolidated and apparently blanket the gentler slopes leading to the volcanic highlands at R.

Structural interpretation of the region is based on drainage and outcrop pattern elements. It is seen that at the upper end of the interior basin, the principle drainage is towards the south along the axis. The area immediately west of the axis is, in part, exposed bedrock. To the east the surficial material is recent alluvium and is probably of considerable thickness. The banded, cuesta-forming sedimentary sequence mentioned earlier is repeated on both the west and east sides of the basin, but with opposing dips. These attitudes resection, using the theorems of projective geometry. The curvature of the Earth was not considered.

The most apparent and interesting feature in this picture is the very black and sinuous lava flow near the center of the field of view. This feature, called the "Malpais" on maps of New Mexico, could almost be mistaken for a lake in a smaller scale reproduction. The lava is very recent in appearance, being obviously younger than anything in the surrounding landscape except for areas of recent alluviation. The flow is approximately 44 miles long, with the lower foot-shaped end about 10 miles wide. The surface appears ropy and reticulated, suggesting lava of the pahoehoe type. The direction of the flow markings and ropy figures, as well as the form of the flow, conform to the general slope of the topography. The narrow belt connecting the broad headward area with the lower foot area, is seen to lie in a fairly narrow valley obviously created by normal sub-aerial erosion. In the upper left corner of the picture, another volcanic flow is visible which apparently is overlying a flat plain identified as part of the "Jornada del Muerto" of Central New Mexico. The recency of these two extensive flows is attested to by their superposition over older Quaternary alluvium, and also over a landscape of fairly recent origin.

Vegetation is visible in the channels of some of the small ephemeral streams that apparently disappear along the margins of the drainage basins at locations A and B.

Bedrock geology is well-exposed, as it is throughout most of the desert country of the southwest. In this photograph, the north end of the San Andres Range is shown, helping to complete the geological picture begun in Fig. 2.

The gently sloping foreland at C near the center of the picture is identified as a probable pediment. An area of complex bedrock geology crops out just east of the narrow "isthmus" of the long lava field. Here, several small cuestas stand out above the general topography at D, which are designated as Dakota sandstone on the USGS Map of Dane and Bachman (Ref. 7). Banded markings in the vicinity of D represent additional beds. These are identified as Mancos shale and undifferentiated Triassic sedimentary rocks on the geologic map. In the San Andres Mountains, several lithologic units can be separated. Just as in Fig. 3, the dark-toned marker strata at E are easily traced. Several different outcrops of this rock unit, (identified as Abo sandstone on the geologic map), impart the general structural and stratigraphic relationships to the interpreter. The core of the San Andres Mountains appears to be composed of a rough textured, fractured mass which underlies the Abo sandstone. These rocks are labled on the geologic map as undifferentiated Pennsylvanian limestone, shales, and sandstone. A mesa with deeply gullied bluffs adjoins the northern tip of the San Andres Range at location F. The rough texture again suggests a fractured and rough-surfaced complex of sedimentary rock with deep gullies near the cuesta face which are suggestive of a less resistant, poorly indurated material. The poorly indurated material is described as being essentially fine-grained silty sandstone and gypsum of the Permian Yeso formation (Ref. 7). The rocks of the mesa are interpreted as having a gentle dip to the northeast, resting on the Abo Sandstone.

The geologic structure of the area is characterized by the west dipping strata of the San Andres Mountains and by the depressed block occupied by the Malpais lavas. A series of en-echelon faults displace the main backbone of the

San Andres Mountains at the north end of the range, and trend north-northeast. Some of the faults are well marked by displacements in the Abo sandstone and marker beds of the Yeso formation. An anticlinal fold is suggested at G, because of the opposing dips in the Abo formation at H and I and the central core of older limestone and shale.

The dominant trend of the mountain range is north. Several large linear mountain ranges can be identified in the upper part of the photograph by the black patches of vegetative cover and by the clouds which hug the crests of the higher ranges.

2.3 PHOTOGEOLOGY OF OTERO MESA AND GUADALUPE MOUNTAIN AREA

Figure 5 was photographed from the V-2, No. 40 rocket at an altitude of about 88 kilometers. The camera was pointed a few degrees south of east, towards the Pecos River and Carlsbad, New Mexico. The camera depression angle was approximately 45.5 degrees. Orientation was accomplished by a graphical, four-point resection method using only a scale and straight edge. The method required that four known control points be located on the ground (or base map), and in the photograph. A flat Earth of no relief is assumed (Ref. 8, pp. 451-456).

In this picture, sharply contrasting bedrock formations are not in evidence. The picture can be subdivided roughly into three to four tonal zones. The darkest tone is represented by the relatively dense pine forest. (Green vegetation is rendered black to dark gray by panchromatic film.) Included in the same tone group but not quite as dark are three volcanoes visible at the south corner

V-2 NO. 40

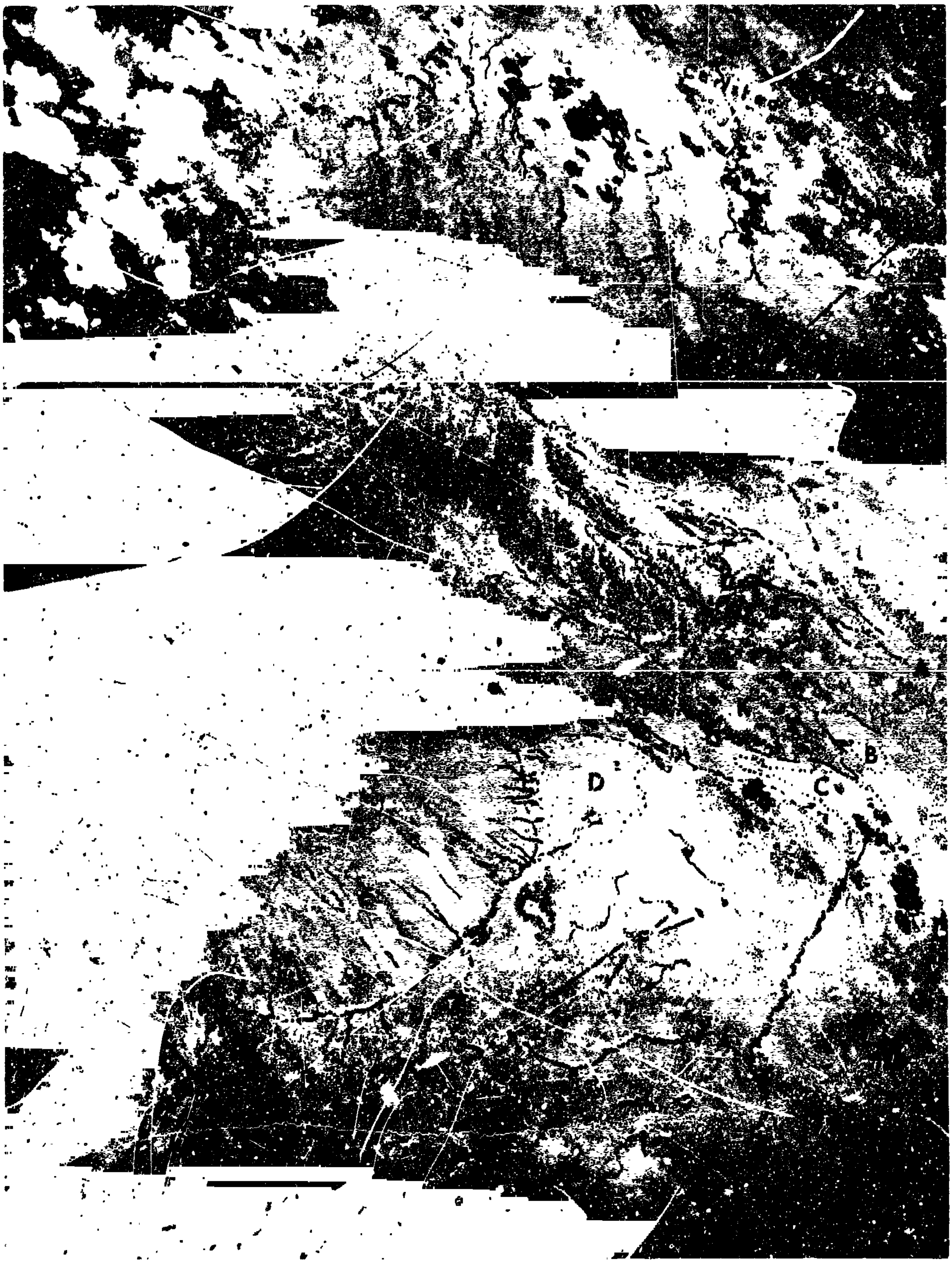
Figs. 5, 5a — Photogeologic interpretation of Otero Mesa and Guadelupe Mountains, New Mexico, showing karst features, possible landslide phenomena, dark tone of forests on pan film.

Tilt (approx.)	44.5°
Direction of Principal Line (approx.)	East

KEY TO LOCATION

A	Interior basin, alkali - salt flats
B	Playa or alkali - salt flats
C	Playa or alkali - salt flats
D	Playa or alkali - salt flats
E	Piedmont alluvial fans
F	Sink holes
G	Possible landslide feature
H	Possible landslide feature
I	Possible displaced blocks
J	Possible displaced blocks

Fig. 5


D
C
B

of the picture. Two intermediate gray zones are discernable: the darker represents the complexly dissected highland area bordering the dark forested areas, while the lighter zone represents the flat area bordered by the rim of Otero Mesa and also the slope leading from the Guadelupe Mountains east to the Pecos River. The lightest tone, a very light gray, appears mainly south of the principal point and presumably results from a patchy cover of alluvium and soil.

Several smaller interior basins or alkali flats can be roughly outlined by their high albedo and by drainage leading in to them. These areas are located to the south of the principal point and are marked A, B, C, and D in the figure. Area A cannot correctly be called a playa because it has drainage leading out of it to the south. However it does appear to be a temporary collection point or low area, and exhibits a high albedo, which is probably the result of saline - alkaline accumulation. Area D appears more similar to a true playa, with no drainage leading out and with a small alkali flat building up at the lowest part.

An extensive alluvial apron consisting of several large coalescing fans is discernable along the south margin of the Sacramento Mountains in the vicinity of location E. The drainage here is parallel and sometimes braided, which is reasonably characteristic of large alluvial fans.

Several features suggestive of mass movement related to landslide phenomena occur at G and H along the edge of the rim of Otero Mesa. Area G is apparently a large landslide which has resulted from collapse of the rimrock strata. Refer to section 5.2 on NASA Aerobee photography for a detailed discussion of the landslide at G. About 20 kilometers north of G another feature can be seen which is suggestive of a large slump or landslide, (location H).

are indicative of a synclinal basin along the axis of the interior drainage basin. The dip of the westerly flank of the syncline appears greater than that of the easterly flank because of the narrower outcrop width of the dark-toned marker stratum (Symbol Pa on half-tone). In addition, the slope of the basin is probably steeper on the west, as is shown by the greater section of bedrock exposed there. Additional evidence is suggested by the trunk stream of the basin being closer to the marker stratum on the west than to the same formation on the east. Several en-echelon faults can be identified by displacement of the marker bed.

Drainage control by fault or fracture systems is visible in several areas, particularly along the west side of the Rio Grande in the vicinity of location T. Several stream offsets are aligned in this vicinity.

Comparison of the photograph with the U.S. Geological Survey Map, Fig. 2 (Ref. 7), reveals that most of the formations broken out by Dane and Bachman are mappable on the photograph. Units visible in the photograph include the Permian Abo sandstone (Pa), marker beds within the Permian Yeso formation (Py: Permian sandstone, gypsum and limestone), the Permian San Andres limestone (Psa), Quaternary-Tertiary volcanics (vol), the main basin-filling alluvial river terrace (Qt), and the recent floodplain deposits of the Rio Grande River. Less well demarcated, but nevertheless separable, are the Precambrian metamorphic rocks of the San Andres Mountains in the lower right corner of the photograph and the core of the Caballo Mountains. The Precambrian complexes are characterized by deep sculpturing and comparatively dark tone, which is believed to be mainly the result of shadows produced by the ruggedness of the outcrops. Some folded marker beds can also be traced within the overlying paleozoic sediments (lighter-toned zone between the Precambrian and Permian rocks).

The photograph suggests that the contact of the Cretaceous Mesa Verde group with basin alluvium extends along the west bank of the main trunk stream of the basin. The geologic map, on the other hand, shows this contact several kilometers west of the railroad.

Some of the units with smaller areas of outcrop cannot be delineated on the photograph, such as those in the southern Caballo Mountains. The number of lithologic contacts that are recorded in the photograph are nevertheless surprising.

Many of the major faults in the area were interpreted without the aid of the map. At location T, for example, the trellis drainage pattern and a weak lineation suggest a fault cutting across the piedmont west of the Rio Grande River.

A sense of relief is more difficult to perceive in this photograph in comparison with the high obliques. The only indication of relief is where the highlands are deeply incised by drainage, such as in the Precambrain outcrops.

2.2 PHOTOGEOLOGY OF THE MALPAIS LAVA AREA

Figure 4 is centered near the north end of the San Andres Range, New Mexico about 100 miles north of White Sands. The depression angle of the optical axis is about 31°, and the ground trace of the principal plane trends approximately N 7° E. The exposure altitude was calculated as 50 miles, (81 km.). Variation in scale along the principal line is represented by the graphical scales on the halftone (Fig. 4a). Orientation was accomplished by four-point graphical

V-2 NO. 40

Figs. 4, 4a – Photogeologic interpretation of the Quaternary "Malpais" lava flow and vicinity, showing an apparent anticline in the northern end of the San Andres Mountains, an apparent pediment, and "pahoehoe" lavas.

Tilt (approx.)	31°
Direction of Principal Line (approx.)	N 7° E

KEY TO LOCATIONS

A	Vegetation in stream channels
B	Vegetation in stream channels
C	Probable pediment
D	Small cuestas, probable Dakota sandstone
E	Marker horizons, dark red Abo sandstone
F	Mesa, gullied bluffs
G	Possible anticline
H	Abo marker horizon
I	Abo marker horizon

Fig. 4

The topography included within the dotted contact appears very hummocky. A large concave scarp suggestive of a breakaway scarp stands out at the head of the hummocky area. Associated with the supposed landslide feature is a large block which may possibly be a displaced segment of the face of the cliff which forms Otero Mesa. This area is bounded by the dotted contact on the north and a possible gravity fault on the east, (conjectured from the apparent repetition of the similar units at I and J).

A number of dark spots marking the terminus of short streams appear at F, a few kilometers east of the rim of Otero Mesa. The dark spots appear to be sink holes such as are found in topography underlain by flat-lying calcareous rocks. The drainage in this vicinity is developing a widely branching, dendritic pattern representative of flat-lying stratified rock which has been jointed or fractured.

The essentially flat-lying calcareous mesa sequence (Ref. 9) laps over the margin of the Sacramento Mountains. The alluvial area at E covers the actual contact, nevertheless the change in topography between mountains and plains is clear cut. No stratigraphic contacts are apparent in the mountainous areas, however the coarser texture of the core of the Sacramento Mountains (pine-covered area) suggests that these rocks differ from those forming the flanks. Similarly, the forested areas in the Guadelupe Mountains may demarcate a different rock unit than the lighter-toned flank areas. The lower slopes of the Sacramento Mountains appear to be dip slopes flattening out towards the south to an almost horizontal attitude at K, near the principal point. The area at K is itself a mesa which rises above the surface of the plain east of Otero Mesa.

The general structure interpreted from this photograph appears to be that of a flat-lying mesa flanking a series of progressively tilted sedimentary strata which are domed up around a core of older more resistant rock. The Guadelupe Mountains appear to be a large cuesta dipping gently to the east and bounded along the west escarpment by a fault. The geologic highway map of New Mexico also indicates a fault bounding the escarpment (Ref. 9). The convex bulge of the fault trace on the photograph is somewhat suggestive of an overthrust. East of the Guadelupe Mountains, the regional dip is apparently somewhat north of east at a low inclination.

SECTION 3

INTERPRETATION OF VIKING 11 PHOTOGRAPHY

3.1 PHOTOGEOLOGY OF EL PASO REGION

Figure 6 is one of the best examples of high-resolution hyperaltitude photography. Over 12,000 square miles in southwest Texas, southeastern New Mexico and northern Mexico are covered. The Rio Grande River, bordered by agricultural fields on its floodplain, traverses the upper left portion of the photograph. The air strips north of El Paso, three railroads entering El Paso, and some highways can be detected with a magnifying glass, even though the picture was taken from an altitude of 136.3 statute miles. Curiously, two Mexican railroads leading south and southwest out of Juarez cannot be detected.

An approximate method for finding the camera orientation was used for Figure 6. The subrocket point was known to be in the vicinity of White Sands, New Mexico, which lies about 78 miles north-northeast of the area at the center of the photograph. Therefore, the depression angle is roughly

$$\text{arc tan } \frac{136}{78} \cong 60° \ ,$$

and the azimuth of the optical axis is south-southwest.

A second method using the principle that the scale numbers increase toward the horizon and are constant along perpendiculars to the principal line was tested and similar results were obtained. The scale of the photograph was determined at several scattered points on the photograph using the U.S. Coast

VIKING 11

"Official U.S. Navy Photo"

Figs. 6, 6a – Photogeologic interpretation of El P o region, showing crater chains, tectonic lineaments, folds, volcanic flows, depositional plain, playas

Tilt (approx.)	60°
Direction of Principal Line (approx.) (Arrow on Principal Line in photo points in direction of tilt – as if observer is looking along camera axis)	South-Southwest

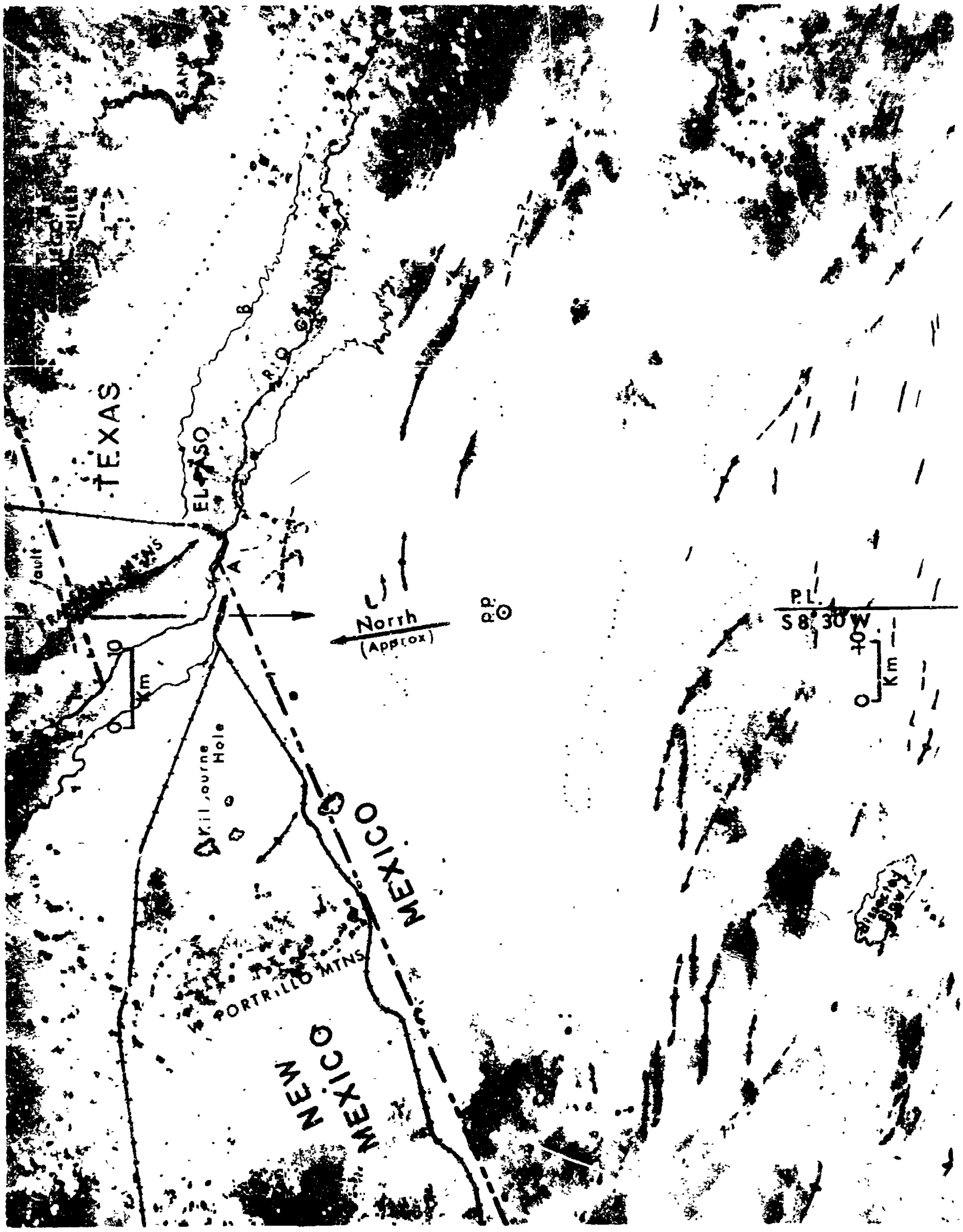
Camera	–	Modified K-25 aircraft
Filter	–	Infrared
Lens	–	Ilex Paragon f/4.5, 163 mm focal length (a right angle prism was attached to lens to enable camera to be mounted in a specific position)
Field of view	–	Vertical 34° 30', Horizontal 42° 20'
Shutter	–	set at 1/500 sec
Aperture	–	set at f/8
Film	–	Kodak Aero Type 1A, high-speed infrared, topographic base; exposure index 100 with red filter

KEY TO LOCATIONS

A Intrusive hills, El Paso ("The Pass")

B Bluffs, river terrace

Fig. 6


TEXAS
MEXICO
NEW MEXICO
PORTRILLO MTNS
North
(Approx)
P.L.
S 8° 30'W
Km
Km
fault

and Geodetic Survey World Air Charts. This enabled estimation of the direction of the principal line. Subsequently, the horizontal scale numbers at two points on either side of the principal point were compared. If S_{x_1} and S_{x_2} are the horizontal scale numbers at the two points, then

$$\frac{S_{x_1}}{S_{x_2}} = \frac{\cos \varphi_1}{\sin (\theta + \varphi_1)} \times \frac{\sin (\theta + \varphi_2)}{\cos \varphi_2} .$$

This equation can be solved for the depression angle θ, in which φ_1, and φ_2 are the vertical angles from the principal point to the two points. (See Ref. 10, Report 1 of NAS 5-3390, for photogrammetric formulae.)

Considerable Quaternary geology and geomorphology can be deciphered, as well as some gross structural patterns. The highly reflecting central portion of the photograph is readily interpreted as a flat, barren area. The absence of surface irregularites is indicated by the uniform texture. High albedo and uniform texture are characteristic of alluvial deposits. Evidence supporting the depositional nature of the plain is furnished by the lack of erosional features and the braided stream channels entering the area. Several arroyos terminate in interior drainage depressions (marked by dotted outlines on the annotated halftone, Fig. 6a). The depressions exhibit very high albedos, and are perhaps the sites of some salt accumulation. The recent alluvium is generally light in tone, except near volcanic sources such as the West Portrillo Mountains.

The Rio Grande weaves across a broad floodplain up to four miles wide. The floodplain is a strath valley cut in an older alluvial plain of small regional gradient. (Darton, 1933.) Three hills formed by andesite porphyry intrusions cause the floodplain to narrow near El Paso. The hills are designated by the symbol A on the overlay. Low bluffs are visible at B, several kilometers removed from the present river floodplain. Normal subaerial erosian augmented by slumping in loose sediments underlying the terrace cap, have apparently pushed the bluffs back to their present location.

Abundant testimony of recent volcanic activity can be gleaned from the photograph. Cinder cones, especially numerous in the West Portrillo Mountains, show well-preserved form and summit craters which can be seen with a magnifying glass; they are probably not older than Pleistocene and may be younger.

Two recent lava flows which have spread out over the alluvial plain are easily identified. One is located immediately north of Kilbourne hole and the other is near the left central edge of the photograph. The dark-toned Quaternary lava flows can be distinguished from the remnants of pre-existing mountains by their shape and drainage pattern. In the area photographed, the lava flows have an irregular, patchy shape and a sinuous drainage pattern, which reflects the essentially horizontal attitude of the flows. In contrast, the older linear ranges have a pronounced backbone or ridgeline and straight drainage channels down the steep flanks. According to Darton (Ref. 11), the recent lavas are mainly scoriaceous basalt, but Tertiary rhyolite, andesite, latite, and colored tuff and ash are also present in the area.

The pre-Quaternary stratigraphy and structure are more difficult to interpret from the photograph alone. Nevertheless, some generalizations are apparent. Considering first the area west of the Franklin Mountains and the Rio Grande, a strong structural grain is produced by the alignment of the topographic highs. Stratification is discernible in some places-for example, in the Franklin Mountains.

The structure of near-buried formations has had a strong influence on later events. The course of the Rio Grande parallels the structural grain and appears to be controlled by bedrock topography. (See Fig. 6a.) Equally striking is the probable bedrock control of the extrusive activity. This is best illustrated by cinder cone alignments in the West Portrillo Mountains. The extrusives may have moved up along bedding or foliation planes, suggesting that the structural trends extend steeply to considerable depth. The structural control of the cinder cones in the West Portrillo Mountains would be more difficult to realize without the aid of small-scale photography, since the bedrock does not crop out in the immediate vicinity.

The structural and stratigraphic relations between the region just discussed and the area east of the Rio Grande are not clear from the photo alone. Strongly folded strata of the Huego Hills appear to be overlain unconformably by strata of Sand Mesa, which are flat-lying or dip a few degrees north, as suggested by the narrowing of the cliff as it is traced northward. It appears that a pediment is forming as the cliff retreats. At the same time, the folded strata beneath the unconformity are exhumed.

Sand Mesa is composed of strata of the Comanche Series (Lower Cretaceous), and the Huego Hills expose Paleozoic rocks, mainly Permian limestone (Sellards et al, 1932). Rocks from Precambrian to Recent crop out in the Franklin Mountains, but west of the Rio Grande the topographic highs consist mostly of Lower Cretaecous and associated Tertiary volcanics, with minor Jurassic beds.

The structural grain so prominent west of the Rio Grande is not present east of the river. A profound structural discontinuity appears to exist between the two areas. The dotted line on the annotated halftone marks the approximate boundary between the eastern front of the Cordilleran system on the west, and the Diablo platform on the east, which evidently escaped Laramide deformation. (See, for example, King, 1959.) A fault has been inferred in this area by some workers (Carta geologica..., 1947).

Two interesting depressions occur east of the Portrillo Mountains. The northern-most is Kilbourne hole; directly south is Hunt's hole. A third depression, Phillip's hole is near the other two but not detectible on the photograph because of its small size. Kilbourne hole is about two miles in diameter, 300 feet deep, and possesses a rim 50 feet to 100 feet high. It is not readily identified as a hole on the photograph, although a more oblique sun angle might produce an identifiable shadow. A 15-foot lava bed, just below the surface alluvium (Ref. 11), prominently rings the hole. The three holes were believed the result ot volcanic explosions.

SECTION 4

INTERPRETATION OF VIKING 12 PHOTOGRAPHY

4.1 PHYSIOGRAPHIC PHOTO INTERPRETATION OF SOUTHWEST ARIZONA AND PART OF SOUTHERN CALIFORNIA

Surficial deposits are pronounced in this photograph. The light tone of the extensive alluvium contrasts markedly with the darker areas of exposed rock. The high albedo of the surficial deposits is due primarily to their relative smoothness and lack of shadow producing irregularities, to their light color, and to the absence of significant vegetation. Desert soils, especially in enclosed drainage basins, are often light-colored because of encrustations of alkaline-saline compounds.

Drainage channels can be seen in surficial deposits as far as Phoenix, Arizona, mainly on the alluvial aprons bordering the major mountain ranges. The drainage is mostly dendritic in pattern, with braided tributary channels in the lower reaches. Drainage systems on the relatively steep piedmont aprons are visible in the photograph mainly because of shadows produced by the steep walls of entrenched streams. Out on the gentler slopes of the intermontane basins, it is thought that drainage channels are visible because of vegetation growing in and along the channels in addition to shadows cast by the walls, shrubs, and debris.

Areas of bedrock are generally identifiable by dark tone. Sculpturing is apparent in the larger scale, bottom part of the photograph and snow-capped peaks can be seen 600 miles distant in the high and rugged mountains east of Los Angeles.

VIKING 12

"Official U.S. Navy Photo"

Figs. 7, 7a — Photo interpretation of physiographic features in southern Arizona and parts of southern California and Mexico. Figures show major fault systems and axial trends of mountains in Basin and Range Province.

Tilt (approx.)	74.5°
Direction of Principal Line (approx.)	Due West
Altitude	230 Km

Camera	—	Modified K-25 aircraft
Filter	—	Infrared 25A red
Lens	—	Ilex Paragon f/4.5, 163 mm focal length
Field of View	—	Vertical 34° 46', Horizontal 42° 42'
Shutter Speed	—	set at 1/500 sec
Aperture	—	set at f/8
Film	—	Kodak Aero Type 1A, high-speed infrared, topographic base; exposure index 100 with red filter

Fig. 7

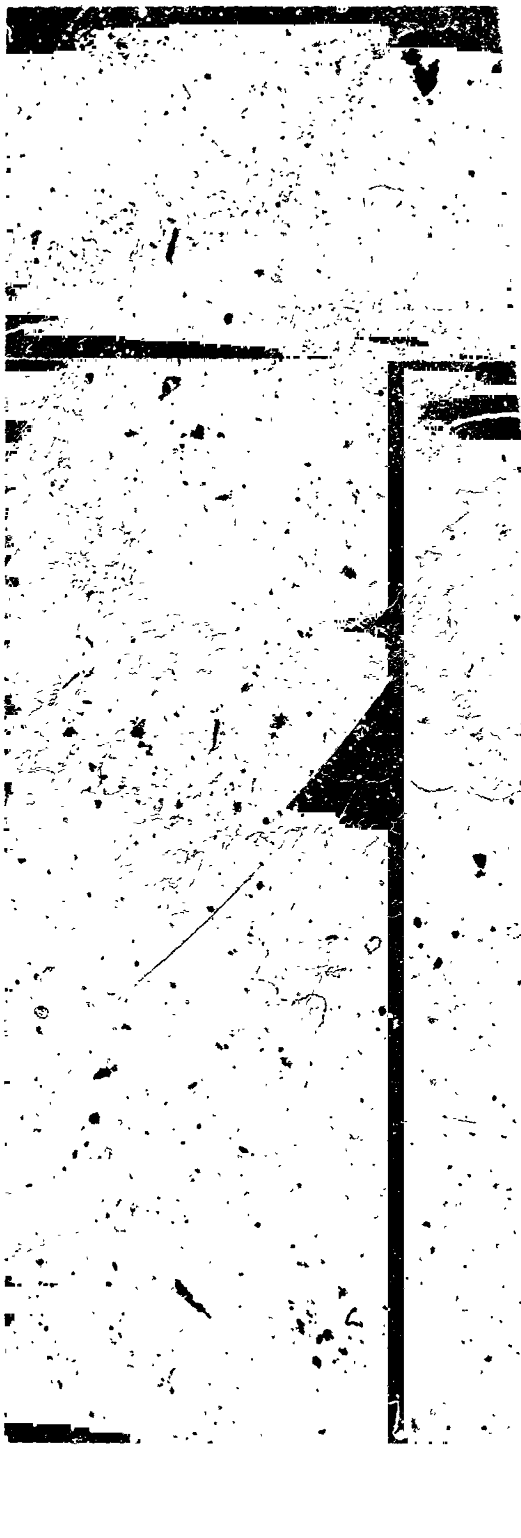


Fig. 7a

Major tectonic features such as the Salton Sink and the tremendous fault systems of California are visible even out close to the horizon. The trace of the San Andreas fault can be followed from the vicinity of Palm Springs to its entry into the coast ranges of California. South of Palm Springs, the trace of the San Andreas is not perfectly clear, but by following its established course, it is seen to follow the east margin of the Salton Sink, paralleling the structural grain of the basin and range country of southern Arizona. The traces of the Garlock, San Jacinto, and Elsinore faults become apparent after careful study of the picture, however these lineations could not be positively identified as being faults if the interpreter had no prior knowledge of their existence and location.

General subparallel alignment of ranges is apparent in southern Arizona. Areas interpreted as bedrock are recognized by their darker tone. Aprons of mountain-derived alluvium, probably coarse clastic deposits, are seen ringing the outcrop areas. Most of these small distinct mountain ranges are elongate in plan, and their crestal traces are plotted as long arrows on the accompanying interpretations. After taking into account any false parallelism owing to foreshortening, it is seen that the majority of the linear ranges in southwestern Arizona follow the same structural grain as delineated by the San Andreas Fault System. Several ranges which have axial trends complementary to the dominant trend, are visible between the Gila and Colorado Rivers in central Arizona. East of Phoenix, this parallelism and linearity of ranges is lost to some extent. Many of the parallel ranges are primarily volcanic in composition, and it appears probable that the volcanism was a widespread occurrence along the same deep-seated tectonic lineaments responsible for the dominant structural grain in that vicinity.

Sev al lineations are visible in the lower part of the picture and are interpreted as fault traces of significant magnitude. The very straight course of the San Pedro River east of Tucson may be fault controlled, although this is not shown on the geologic map of Arizona, (Ref. 15).

In view of the small scale of the photograph, only very general lithologic information is recorded. Nevertheless, three types of surfaces, which can be suggested as typical of basin and range desert physiography, can be delineated in this region on the basis of tone and texture. These surfaces are: (1) elevated highlands of exposed rock; (2) transport aprons (pedimonts, bajadas and alluvial fans); and (3) playas.

In this photograph the highland areas exhibit the darkest tone and most irregular texture. These qualities are chiefly the result of random shadow patterns created by rough and angular rock outcrops in the more mountainous topography. A shadow is produced when the slope of a surface is greater than the elevation angle of the sun (measured from the horizon to the Sun). The photograph was taken at 3:00 p.m. on the fourth of February; therefore, the Sun elevation was roughly thirty degrees.* Some larger shadows can be seen in ranges in the lower part of the photograph.

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* The sun angle can be determined precisely by the following equation,

$$\sin h = \cos \theta \cos \varphi \cos \delta \cos \alpha + \sin \theta \cos \varphi \cos \delta \sin \alpha + \sin \delta \sin \varphi,$$

where h is the elevation of the Sun above the horizon, θ is the sidereal time, φ is the latitude of the object casting the shadow, and α and δ are the right ascension and declination of the sun obtained from the American Ephemeris and Nautical Almanac.

In addition to the shadows, the ranges appear darker than the piedmonts and basins because of sparse vegetation. The vegetation of the desert ranges in this region consists principally of shrubs - for example, creosote bush and burro weed - which average two to three feet in height. Both the dark tone of the shrubs and their shadows contribute to the darker tone of the ranges. Furthermore, the bedrock of the ranges is generally darker than the detrital material on the piedmont slopes, owing to the higher percentage of ferro-magnesium minerals, basic volcanic glass and desert varnish.

The piedmont slopes are intermediate in tone and texture and grade into lighter-toned zones as the centers of the basins are approached. Several reasons may account for the darker tone of the upper piedmont slopes relative to the zones of lower gradient. Observations in the field and from low-flying aircraft reveal that the upper slopes, although sparsely vegetated, support more vegetation than the lower slopes which are essentially barren or support only scattered halophytes adapted to the alkaline soil. Furthermore, the upper slopes are commonly strewn with cobbles and boulders which are darker in color owing to dark minerals and, in many cases, desert varnish. Both shrubs and boulders — usually absent on the lower slopes — form shadows when the Sun is not at the zenith which contribute to the overall darker tone.

Some of the advantages and disadvantages of high oblique photographs are exemplified by this photograph. High obliques present a view of the landscape resembling that from a mountain top or other elevated vantage point. It is, therefore, a view which is familar to us. Even without stereoscopic coverage one gets a sense of relief, especially with the aid of shadows. Much greater coverage is achieved in oblique views; therefore, the angle of view is an offset to altitude and lens field of view. On the other hand, linear features are not seen in their true directions owing to foreshortening. As the horizon is approached, all linear features appear to trend perpendicular to the principal line of the photograph. Consequently, patterns of linear elements are obscured to various degrees. Drainage patterns, fault patterns, and the relationships between tectonic and igneous processes are less well revealed. In addition, areas shielded by highlands are invisible as well as rivers incised below the surface.

4.2 PHOTOGEOLOGY OF GILA - SAN FRANCISCO RIVER REGION, NEW MEXICO AND ARIZONA

Figure 8, Viking XII, images a large area of New Mexico, Arizona, and California. The picture is centered on an area midway between the San Carlos and Theodore Roosevelt Reservoirs which are located east of Phoenix, Arizona. Parallel to the horizon, the image extends from the volcanic flows of Cerro Pinacate on the Mexican coast of the Gulf of California to the Painted Desert region of Arizona, a distance of more than 300 miles (450 km). From the bottom of the picture to the top, in the direction perpendicular to the horizon, the image extends from the vicinity of Hurley, New Mexico, to the Coast Ranges of California, a distance of more than 600 miles (1000 km).

The camera altitude was 163 kilometers with a depression angle of 23° 48'. The ground (map) azimuth of the principal line was found by plotting the principal line on the map by inspection and was measured as north 83° 30' west.

Image resolution in the Viking 12 pictures is considered good. Baumann and Winkler (Ref. 3) stated, "The finest line which could be measured was .001 inch wide, which was probably only one-fourth the capability of the lens --." Assuming that the measurement by Baumann and Winkler was taken from an

VIKING 12

"Official U.S. Navy Photo"

Figs. 8, 8a — Photogeology of Gila-San Francisco River region, New Mexico, showing tectonic lineaments, volcanic flows.

Tilt (approx.)	66°
Direction of Principal Line (approx.)	N 84° W

KEY TO LOCATIONS

A	Small stream channels, example of fine detail
B	Arcuate trace of San Francisco River
C	Lineaments, fault oriented
D	Piedmont alluvial slopes
E	Recent volcanic flows
F	Recent volcanic flows
G	Recent volcanic flows
H	Probable old volcanoes

Fig. 8

LOCKHEED
CALIFORNIA COMPANY


MT HUMPHREYS
MOGOLLON PLATEAU
ARIZONA
NEW MEXICO
WHITE MTNS
PHOENIX
Gila
San Fran
Cerro Pinacate
0 10

original negative, a corresponding line width in Figure 8 which is roughly a 1.5 diameter enlargement, would be 0.015 inch (0.06 millimeter). Some of the smallest discernable detail in Fig. 8 is near A in the lower part of the picture, where small tributary streams are just resolved. These small streams are roughly 0.07 to 0.09 millimeters wide, which generally agrees with the more all-inclusive value given by Baumann and Winkler. Ground resolution in Fig. 8 for round or square objects can be estimated from the tailings pond near the town of Hurley in the lower left corner of the picture. A small black spot – the image of a tailings pond - can be seen just left of Hurley. The image is on the verge of being unsharp, but is identifiable with the aid of a topographic map. The image diameter was measured as 0.3 millimeters, or about 5 times larger than the width of the small streams mentioned earlier.

Summarizing, it becomes clear from viewing the photograph that the maximum resolution as calculated above is widely variable even in areas of fairly constant scale number. The best resolution is obtained where linear features contrast sharply with the background, such as those contrasts produced by shadows of incised stream courses. Equidimensional objects are much more poorly resolved than linear features, and in Fig. 8 are only about one-fifth as well resolved as linear features.

Most of the area covered in Fig. 8 is also part of Figs. 7 and 9. Comments about lithology are included in the discussions associated with those pictures. The present discussion will be concerned mainly with structural considerations, because certain structural features are brought out best in the lower part of the photograph.

The lineaments, drainage, and the axial trends of mountains in the lower central part of the picture bring out an apparent arcuate structural pattern in the mountainous topography east of the Arizona - New Mexico border. The upper part of the course of the San Francisco River is aligned with a valley to the south forming a broad arc which is convex to the west (location B in Fig. 8a). The river follows the arcuate trace to a point several kilometers south of location B and then turns sharply to the west, cutting across the general topographic grain.

Immediately west of the New Mexico-Arizona border, several relatively straight lineations are apparent which suggest faults or fractures. These lineations represent a system of faults shown on the geologic map (Ref. 7), which bound the east flank of the San Francisco and Saliz Mountains. Most of the straight lineations visible in the lower part of the photo are stream courses controlled by faults or fractures. However, saddles caused by faulting are often lined up across ridges and as a result are seen as lineations in aerial views. These lineations are often not as well-defined as those formed by incised stream courses. The lineations at location C, near the lower margin of Fig. 8a, are apparently fault-controlled alignments of saddles and ridges.

The majority of lineations shown on the annotated half tone cannot be correlated one by one with faults or bedrock contacts shown on the Geologic Map of Southwestern New Mexico (Ref. 7). However, the general northwest-southeast trend of the system of lineaments at C can be correlated with a similarly trending system of faults shown on the geologic map just north of the town of Hurley. A system of strong lineations near the Arizona border just above B on Fig. 8a, is apparently a system of faults bounding the San Francisco and Saliz Mountains which are shown on the geologic map (Ref. 7).

A feature which may be drainage channels that have developed along the traces of a fold is delineated just above B. An alternative interpretation is that the "U" shape is an illusion created by foreshortening, which makes it appear that opposing branches of parallel stream systems are connected.

The appearance of the piedmont alluvial aprons bordering the Mogollon and Tularosa Mountains at A and D suggest initial dip slopes in an area covered by a veneer of volcanic ash or flow material. A unit of this fairly recent volcanic material is outlined near location A, and a prominent scarp truncates the westerly boundary of this unit.

A series of volcanic flows which exhibit a peculiar "fuzzy" appearance are visible at location E. The light is coming from the southwest in this picture and practically all of the slopes which face towards the southwest have a relatively light tone with the exception of the volcanics at location E (center left) and a few other areas covered by extrusives, such as at F and G. These outcrops of volcanics are not so highly reflecting on slopes facing the light source as are other rock types. It is thought that the characteristic is due to the very rough surface of some pyroclastics and highly scoriaceous flows.

Two conical peaks can be seen at H near the bottom central part of the photograph which look like old, inactive volcanoes with deeply dissected flanks. No individual volcanoes are shown on the geologic map of the area, but the map does indicate that the area is covered by basalt and basaltic andesite flows of Tertiary and Quaternary age.

4.3 PHOTOGEOLOGY OF MIMBRES MOUNTAINS AND VICINITY, NEW MEXICO

Figure 9 covers a large part of Arizona and a part of southwestern New Mexico. An imaginary line can be drawn from the lower left corner to the upper right corner, roughly separating an area of light and dark patches from an area of more uniform, medium-gray tone. The upper left area corresponds to the basin and range region of New Mexico and Arizona, while the lower right area of darker tone is the southwestern extremity of the Colorado Plateau. The more uniform tone of the plateau region results from the absence of basins accumulating alluvium, a characteristic of the more structurally stable plateau.

Several prominent features are immediately apparent in Figure 9. At location A in the lower left quadrant, the Mimbres Mountains can be identified. The main ridge line is a part of the continental divide, with east-running drainage emptying into the Rio Grande at the bottom of the picture. It appears that the rocks comprising the east-facing mountain front are dipping the same direction but more steeply than the slope, and hogback topography is suggested. Careful examination of the west slope of the range in the vicinity of location B reveals that the drainage pattern is dendritic with subparallel branches. It is suggestive of a dip slope which may have been slightly deformed into the shape of a shallow syncline. In addition, near the crest of the range the headwater extremities of some of the drainage channels are recurved abruptly towards the south, sugges-

VIKING 12

"Official U.S. Navy Photo"

Figs. 9, 9a — Photogeology of Mimbres Mountains vicinity, New Mexico, and part of southeastern Arizona, showing dip slopes and two types of playas with different albedos.

Tilt (approx.)	60°
Direction of Principal Line (approx.)	N83 W
Altitude	141 Km

KEY TO LOCATIONS

A	Crest of Mimbres Mountains
B	Dendritic drainage pattern
C	Tailings ponds
D	Playa, high albedo – probable alkali coating
E	Wilcox playa, low albedo – may be clay-encrusted
F	Recent volcanic deposits

Fig. 9


PHOENIX
SALT
GILA
RIVER
ARIZONA
MEXICO
RR
TUCSON
Hurley
C
D
E

ting structural control by exposed stratified rock. Two structural interpretations present themselves. The first is that the Mimbres range is one flank of a broad syncline developed in a thick section of strata. The other interpretation is that the Mimbres Range is a complete anticline which has been partly dissected and eroded through at the crest. The latter hypothesis appears to be more nearly in agreement with the map of Dane and Bachman (Ref. 7).

Just east of the crest of the Mimbres Mountains at F on the east-facing flank of the range are several extensive fan-shaped areas which look like very large alluvial fans. The geologic map (Ref. 7) indicates that these deposits are actually a series of extrusive andesites, latites, and interbedded sedimentary rocks of Tertiary age.

Several large and deep arroyos which terminate in the Rio Grande, are visible near the bottom of the picture. The arroyos are parallel, deeply incised, and have very few smaller tributaries. (The Rio Grande is located a few kilometers east of the area shown at the bottom of the picture - see Fig. 3 for coverage -). The arroyos are unusually large, straight-walled, and wide, creating the appearance that they were gouged out by torrential runoff of cloudburst proportions, possibly by sediment-charged runoff waters or even by a highly abrading medium such as a mudflow.

At location C near the top center of the lower left quadrant, a prominent white spot is visible which is clearly not a natural feature. The spot is several kilometers in length and breadth, suggesting a scar from a large earth-moving operation. Indeed, the spot was identified from United States Geological Survey topographic maps as a series of rectangular tailings ponds which probably were dry when the pictures were taken except for a very small pond represented by a dark speck near the center of the white area. The very high albedo is seen to compare with that of the playa at location D, a little higher on the picture near the left margin. This similarity would suggest that there is a chemical residue in the dry tailings ponds somewhat like a playa salt, probably a result of leaching resulting from hydraulic mining operations. The town of Hurley adjoins the tailings ponds a kilometer or so to the north but cannot be seen, nor can other towns or cities be seen directly in this photograph. Although cultural features such as roads and buildings are not visible, intensely cultivated areas are usually identifiable by their "salt and pepper" or "patchwork quilt" appearance. Cities can sometimes be identified, however, as a featureless gray spot surrounded by the patchwork of agricultural fields.

Two types of playas are evident in this picture. One type is characterized by the playa mentioned previously (see point D in the upper left quadrant), which exhibits an extremely high albedo. This may be indicative of a dry, hard, mud-encrusted surface having a thin surface coating of bleached alkaline material. The second type of playa can be seen at location E in the upper left quadrant. This playa, the Wilcox playa, is slightly mottled and medium gray in tone, with a light halo around the margins - possibly indicating a damp or moist surface. On the other hand, the lower albedo and mottled tone may indicate a clay-encrusted playa. According to Neal (Ref. 16), clay-encrusted playas are characterized by a "puffy" surface layer, approximately six inches thick, composed of loosely consolidated clay and silt mixed with crystallized salt - all deposited by evaporating ground water. Only meager data is available concerning photometric properties of such surfaces, and it is believed that more investigation of these properties would prove valuable.

Alluvium can be separated from bedrock, but within the areas of outcrop, individual formations are not distinguishable. The Mimbres Mountains, for example, are composed of a complex mosaic of Paleozoic sediments and Tertiary igneous rocks, but the contacts are not visible. This may be partly due to excessive shadow which imparts an overall dark tone to the range. A higher Sun angle would be preferable. (The Sun angle was about 30°).

SECTION 5

INTERPRETATION OF 1963 NASA AEROBEE PHOTOGRAPHY

5.1 PHOTOGEOLOGY OF WHITE SANDS NATIONAL MONUMENT

Figure 10, and the following photograph, Figure 11, were taken from 70 mm cameras mounted in NASA Aerobee Rocket number 4.87GT launched from the White Sands Missile Range on June 17, 1963 at 11:00 a.m., Mountain Standard Time. These Aerobee photographs were the latest hyperaltitude pictures available up to September 1963. Figure 10 is the 96th of the sequence taken from camera No. 2 of the two-camera system. Each camera pointed aft 33.25° from the long axis of the vehicle. The lens was a standard Schneider Xenotar (150 millimeter focal length) stopped to f/11 with the shutter speed set at 1/1000 of a second. The cameras were loaded with Kodak Infrared Aerographic film with an ASA number of 125. A Wratten 25A light red filter was added reducing the effective ASA number to 64.

Altitude and location data were provided by radar tracking equipment. The altitude was recorded as 109.5 km. Orientation was achieved by locating the ground image of the principal point and then calculating the depression angle with the aid of the known altitude (refer to Report 1 under this contract for photogrammetric calculations). The Ground azimuth of the principal line was measured directly from the map. The values obtained for depression angle and azimuth were 63° and N 26° E respectively.

The photograph is centered about 16 kilometers west of Alamogordo, New Mexico. The towns of Tularosa and Alamagordo are clearly visible, including

1963 NASA AEROBEE

Figs. 10, 10a — Photogeology of part of White Sands National Monument showing differentiation of sand deposits, parabolic dunes, coalescing alluvial fans.

Tilt (approx.)	27°
Direction of Principal Line (approx.)	N 26° E

Camera	—	Maurer Model 220, 70 mm.
Filter	—	Wratten 25a red
Lens	—	Schneider Xenotar 150 mm focal length
Shutter	—	Set at 1/1000 sec
Aperture	—	Set at f/11
Film	—	Kodak Infrared Aerographic; exposure index 125, reduced to 64 through red filter

Fig. 10

Fig. 10a

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smaller secondary streets. A railroad and several main highways can be identified as well, as a large airbase outside of Alamogordo. A rocket sled course is visible along the east edge of the dune area.

The area of extremely high albedo-equivalent to the albedo of the scattered clouds around the margin of the photograph - is occupied by gypsum sand. Westward the gypsum grades to quartz sand with some gypsum, which in turn grades to clay, quartz sand, gypsum, and gravel (Ref. 17). The gypsum and quartz sand deposits are mappable on the photograph by thier relative albedos. The deposit containing clay and gravel is located off the photograph to the west. The deposits outline a large deflation basin, and much of the excavated material has been piled into dunes on the plain immediately east of the basin. Lobes along the front of the dune area line up roughly with saddles in the San Andres Mountains to the West and within the area the dunes are identifiable as parabolic, with points tapering windward two miles or more.

A piedmont area, outlined by dashed contact lines on Fig. 10a, borders the Sacramento Mountains east of Alamogordo and Tularosa. The braided drainage pattern and conical shape of some of the individual lobes making up this strip suggest an area of coalescing alluvial fans.

A number of relatively wide drainage channels extend down the gentle slope of the Tularosa Valley, away from the piedmont alluvial fans. These channels are evidently collection channels in which water escaping from the foot of the alluvial fans is transported towards the bottom of the basin. Small meanders appear to be starting in the lower portions of the stream courses as the border of the dune area is approached, indicating low gradient.

A series of benches is seen on the lower slopes of the Sacramento Mountains east of Alamagordo with the attitude of bedding apparently horizontal. These rocks are identified as Pre-Pennsylvanian Paleozoic rocks on the small scale map of New Mexico compiled by the New Mexico Geological Society (Ref. 9).

5.2 PHOTO INTERPRETATION OF APPARENT LANDSLIDE PHENOMENA, OTERO MESA, NEW MEXICO

Figure 9 was taken at an altitude of 58 kilometers, 71 seconds after launch. The camera axis was plunging 60° from the horizontal, with the principal point centered about 50 kilometers northeast of the White Sands Proving grounds at the foot of Otero Mesa, which adjoins the Sacramento Mountains.

The most interesting feature revealed by this photograph is the area near the center of the picture and outlined by the dotted contact at B. The area is oval to lobate in shape and appears hummocky and rough. A very sparse pattern of tributary channels funnels into the trunk stream which cuts across the lower end of the area. The overall appearance suggests a large landslide with good interior permeability. In support of the landslide contention, it is seen that a dark-toned marker bed lies immediately below the mesa-forming cap at A near the center of the frame. The trace of this marker bed stops at the contact of the supposed slide. However, to the right near the principal point several dark-toned blocks are seen which resemble the marker bed and its underlying outcrop sequence. These separated blocks apparently have anomalous or at least different bedding attitudes than the adjacent flat-lying undisturbed sequence. The blocks may be part of the landslide or slump feature and possible were shoved along in front of the main mass.

1963 NASA AEROBEE

Figs. 11, 11a — Photo interpretation of apparent landslide phenomena, Otero Mesa, New Mexico, showing hummocky and rough topography extending downhill from the rim of Otero Mesa. A possible breakaway scarp and the disintegrated pattern of drainage is also noticeable within the roughly oval hummocky area.

Tilt (approx.)	30°
Direction of Principal Line (approx.)	S 80° E

KEY TO LOCATIONS

A Marker bed below mesa surface

B Possible landslide feature

Fig. 11

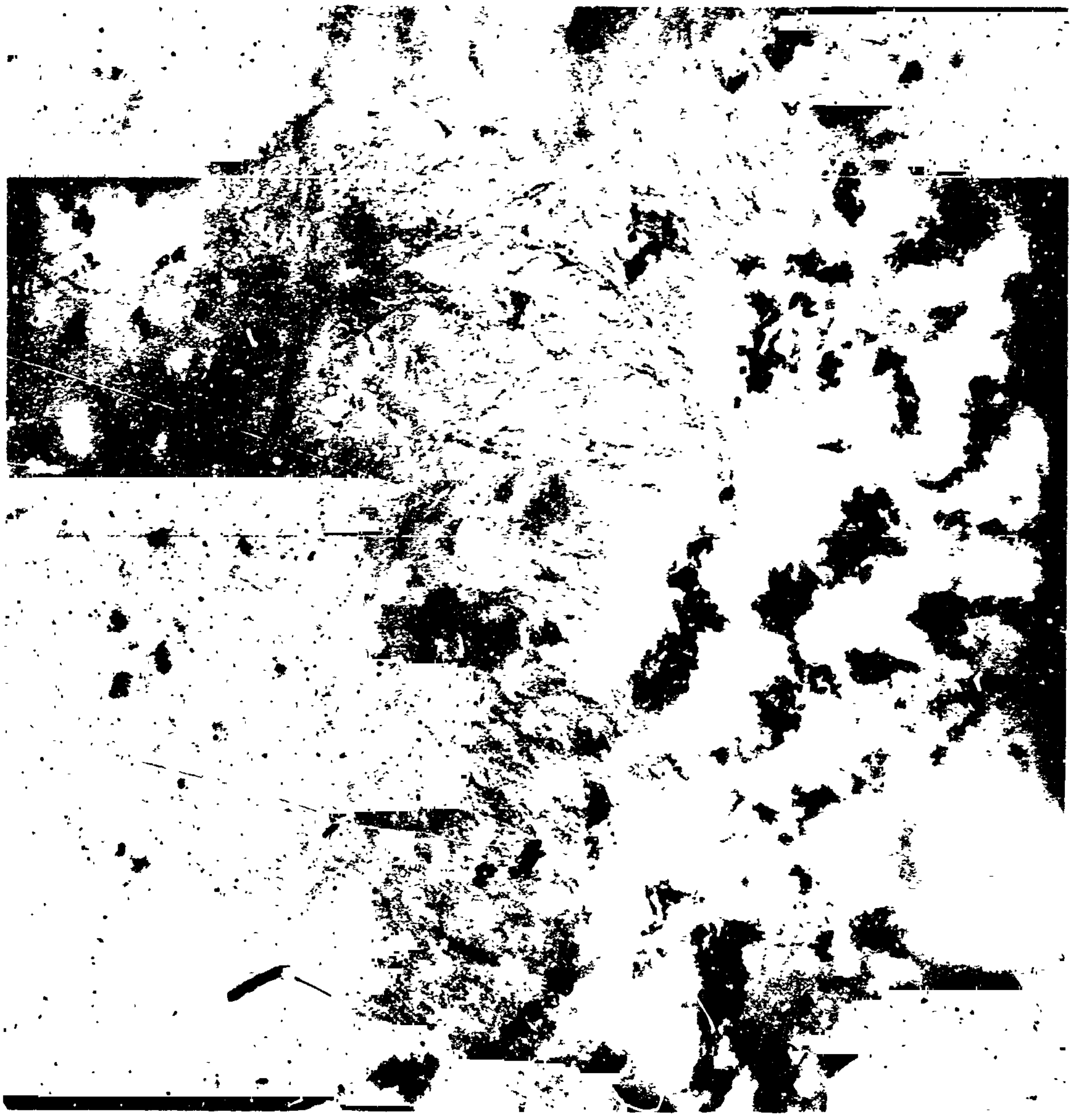

Fig. 11a

No indication of faulting or landslide debris is noted in the available references covering this area (Refs. 18, 19). The Carlsbad sheet of the 1:250,000 scale topographic series, U.S.G.S., shows that the slide area is rough and hummocky and is traversed by a canyon named "Rough Canyon," probably the canyon at B in Fig. 9a. This name is undoubtedly very descriptive of the topography and could well characterize a blocky landslide topography.

Recapitulating, the purported landslide feature appears to be a hummocky veneer of broken rock material sloping gently to the southwest marked by only a few drainage channels. The feature is quite extensive being about 8 kilometers long and 5 kilometers wide. It is flanked by several very large and apparently discordant blocks of Pennsylvanian sedimentary rock. Apparently the slide occurred in the rim-rock capping the mesa, which may have been undercut or weakened by failure of less competent underlying material. The appearance and possible mode of occurrence may be similar to that of the Blackhawk Slide in Lucerne Valley, California. The Blackhawk Slide, described by Shreve (Ref. 20), is a very large, ancient landslide feature which supposedly occurred when a competent cap rock was undermined by erosion. Shreve suggests that the Blackhawk Slide rode on a cushion of air as it plunged down the mountain, spreading out over a large area as it reached level ground.

SECTION 6
CONCLUSIONS

The study of the White Sands rocket photography reveals that considerable information about the Earth's surface is recorded on film that was returned from altitudes up to 150 miles. Geomorphic and physiographic features such as pediments, alluvial fans, hogbacks, dip slopes, mesas, playas, deflation basins, sand dunes, mountain ranges, volcanoes and lava fields are identifiable on the photographs.

Some large surficial deposits are separable in this desert region. Relative albedos appear reliable criteria for separating playas, bajadas, and upper piedmont slopes. The upper transport slopes have a darker tone and more irregular texture than lower slopes of the bajadas. Playas, in turn, have a higher albedo and more uniform texture than the bajadas. The clay playas appear to be slightly darker in tone than the salt playas, which have albedos comparable with clouds.

Drainage systems are mappable, and these were found useful in interpreting slope directions, relief and geologic structure. Since relief is generally not evident, drainage is valuable in separating highlands from transport slopes and basins. In some cases the approximate steepness of the slopes can be inferred from drainage.

Bedding and tectonic lineations are revealed by drainage patterns in several photos. Furthermore, karst topography is suggested by stream configuration and sink holes (Plate 5).

Dense vegetation is readily identified if both infrared and panchromatic photographs of the same area are available. If not, it may be difficult to distinguish vegetation from rock outcrop (especially basaltic lava) at ground resolutions poorer than 100 meters. The sparse shrub vegetation covering much of the region is not visible.

The composition of the consolidated rocks (i.e. bedrock units) is in general impossible to determine. In a few cases sediments can be identified by their bedding, and karst topography of course suggests carbonates. But for the most part granites, sandstones, shales, metamorphics, etc. can exhibit similar appearances. Fresh volcanics have a diagnostically black, uniform tone, and are mappable in many places. (Their association with volcanoes is, of course, an important aid to identification.)

Although the rock type may be indeterminable, the individual rock units can commonly be mapped. This is especially true of tilted beds whose outcrops are persistent for several miles. In some bases the dip of the beds can be estimated from drainage patterns or dip slopes. Non-bedded formations were outlined on some photographs by their gross texture (indicating ruggedness of the outcrop), or by tone or drainage characteristics.

Structural features such as large folds, mass movements, and major faults are well displayed in some photographs. Faults are most easily distinguished when contrasting surfaces have been juxtaposed by movement.

The chief advantage of hyperaltitude photography is the large coverage possible. Gross structural features are readily apparent in some cases, such as the synclinal nature of Jornado Del Muerto (Plate 2). Furthermore, hyperaltitude photography provides the most expedient means of discerning the spatial relations between large surface features, such as the relation of regional structure to volcanism, drainage to topography, surficial deposits to rock outcrops, etc. Costly mosaics of thousands of conventional aerial photographs would be needed to achieve similar perspective, and mosaics have the important disadvantage of showing false tonal gradations and distortions which are not present in large-area hyperaltitude photography.

APPENDIX A

SOME REMARKS ON PHOTOGRAPHIC SYSTEMS AND MIMUMUM RESOLUTION

Owing to so many variables, it is difficult to lay down the specifications for an optimum hyperaltitude photographic system. The means of obtaining the photography depends in part on the nature of the information desired. For example, if gross relations such as regional tectonic trends are sought, large coverage and small scale are necessary, and resolution is not a prime factor. A short focal length camera with a wide field of view, yielding ground coverage 200 km or greater in diameter, would appear to be suitable for broad coverage.

If it is desired to resolve individual features rather than gross spatial relationships, high resolution is required and one must go to long focal length cameras. The great advantage of hyperaltitude photography is the capability of obtaining small-scale photos with broad coverage. Nevertheless, if conventional photographs of the area of interest are not available, large-scale photographs similar to conventional aerial photographs could be obtained from satellites. (See Rosenberg, 1958.) In this case, a multiple camera system would be expedient. Cameras of several focal lengths could capture [illegible] as well as broad coverage of an area.

The following table attempts to summarize a few of the interpretability factors involved in rocket photography. Threshold values for ground resolution are listed for a variety of physical features, assuming an image resolution of .10 mm. The values for ground resolution are very rough because several important factors are not considered, such as contrast with surroundings, and the masking effects of vegetation and haze. The numerical values were derived from Viking 11 and Viking 12 photographs of the southwestern United States and should be considered representative of that terrain only. Other camera systems photographing other areas could be expected to produce considerably different values of ground resolution; nevertheless, the values listed in the table do give a feeling for the type of detail resolved by the relatively simple Viking camera systems, and may give an insight into the photographic requirements necessary for geologic interpretation of hyperaltitude photography.

INFORMATION FROM ROCKET PHOTOGRAPHY

—Some Average Values For Photographic Parameters—
(Assumed image resolution — 10 lines per millimeter)

Information	Tilt	Minimum Ground Resolution (a)	Equivalent Scale No. on a 1.5 Diameter Enlargement (200 mm. x 250 mm. print)
Topographic Expression			
Relief	High Oblique	450 meters	3,000,000
Sculpturing (divides Canyons channels and other surface features)	Immaterial	300 meters	2,000,000
Geomorphic Expression			
Major drainage (Rio Grande etc.)	Vertical	450 meters	3,000,000
Tributary drainage (arroyos, streams)	Vertical	150 meters	1,000,000
Surfaces of Erosion and Deposition Terraces Bajadas Pediments	Immaterial	200 meters	1,350,000
Playas	Immaterial	1000 meters	6,500,000
Structural Expression			
Large faults (San Andreas etc.)	Immaterial	450 meters	3,000,000
Smaller faults Fracture Systems	Vertical to Low Oblique	100 meters to 150	800,000
Folds, Domes, etc.	Vertical to Low Oblique	Variable Depending on Size of Structure	
Areal Geology—			
Prominent Contacts	Vertical	Variable Depending on Size of Structure	

(a) Ground Resolution is defined as the ground dimension equivalent to one line - plus-space of a standard pattern, at a specified image resolution.

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